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# New Fast Shower Max Detector Based on MCP as an Active Element

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**Abstract.** One possibility to make a fast and radiation resistant shower maximum (SM) detector is to use a secondary emitter as an active element. We present below test beam results, obtained with different types of photo detectors based on micro channel plates (MCP) as secondary emitter. The SM time resolution - we obtained for this new type of detector is at the level of 20-30 ps. We estimate that a significant contribution to the detector response originates from secondary emission of the MCP.

## 1. Introduction

The first proposal to use secondary emitter materials as an active element in sandwich type calorimeters can be found in the reference [1]. This approach allows the development of a new type of detector that is highly radiation resistant and fast. The measurements with such a type of element were performed with a micro channel plate (MCP) as an electron multiplier. With the recent progress of the Large Area Picosecond Photo Detector collaboration [2], the cost may decrease sufficiently to allow practical construction of this type of detectors. An alternative approach to achieve a calorimeter with precision timing capabilities is presented in [3].

The principle of operation of the shower maximum detector (or calorimeter) is the following. High-energy particles passing through absorber material in sandwich type calorimeters produce secondary particles (e.g. positron electrons pairs, gammas, etc.) that are detected by MCPs. The generation of secondary particles in the calorimeter will be referred to as a shower. The response of the MCPs to the secondary particles is proportional to their number, which in turn is proportional to the energy of the initial particle.

Most of the secondary particles in the showers have low energy, where the MCPs detection efficiency is high. But the low energy component of the showers is not well investigated, and even reliable Monte Carlo simulation is limited by the minimal energy of the secondary particles to 100 keV. Therefore, to explore the feasibility of a shower maximum detector based on MCPs as the secondary emitter we started with experimental measurements. The goal of the measurements was to obtain time resolution (TR) of the MCP, placed inside of the absorber material. We also performed measurement at 120 GeV proton beam with start and stop counters. The goal was



to estimate what time resolution we can get for the minimum ionizing particles. We did not use any absorber material between the start and the stop counters in the measurement.

## 2. Description of the MCPs used in the measurements

We used two types of photo detectors based on MCPs. One of them was a Photek 240 with superb time resolution (TR). Main parameters of the Photek 240 were measured and presented in [4]. The Photek 240 has a 41 mm diameter circular sensitive area. The input window of the phototube is made of 9 mm thick quartz which enables extended UV quantum efficiency. The single photoelectron time resolution (SPTR) was measured to be 40 ps. The output signal time shift is limited to 3.9 ps across the sensitive area of the Photek 240.

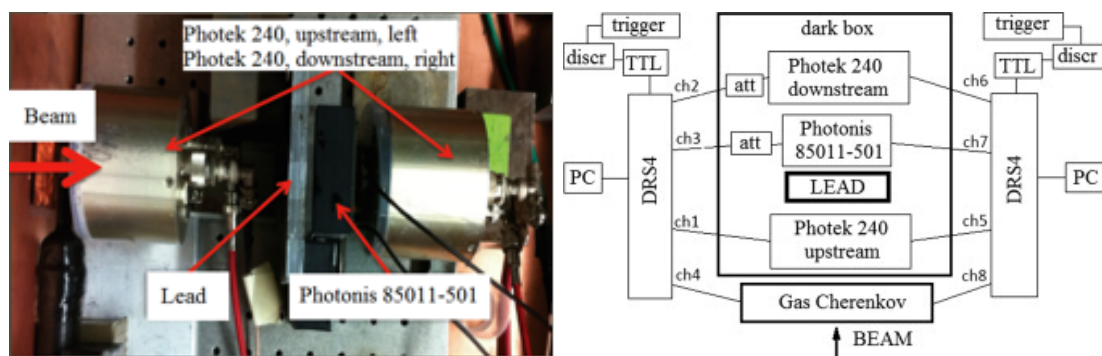
The second type of the MCP-PMT used was a Photonis 85011-501 which is composed of 64 pads, arranged as an 8x8 matrix. The size of each pad is 6x6 mm<sup>2</sup>. 16 central pads (4x4 matrix) were connected together making a sensitive area of 24x24 mm<sup>2</sup>. The input window is made of UV Grade Fused Silica with a thickness of 2 mm.

## 3. Test beam setup

We used the Fermilab Test Beam Facility (FTBF), which provided proton beams from Fermilab's Main Injector accelerator at 120 GeV/c, as well as secondary positron beams with 12 GeV/c and 32 GeV/c. Detectors were located inside of a dark box lined with copper foil for RF shielding (Fig. 1). Trigger was based on a 10x10 mm<sup>2</sup> scintillation counter. The three detectors (two Photek 240 and one Photonis between them) were placed in line. A stack of lead generating a shower, when high energy particle pass through it, was placed before MCP-PMT (Photonis 85011-501 in this case, Fig. 1). The Photonis 85011-501 was swapped with the second Photek 240 in some of the measurements, without any modification to the cabling.

Photek 240 (start counter), upstream Photonis 85011-501 and downstream Photek 240 were placed on the optical table (for normal particle incidence). A stack of lead plates can be seen to the left from Photonis 85011-501 detector. A Cherenkov counter was located before the dark box (in the beam path, not shown in the picture).

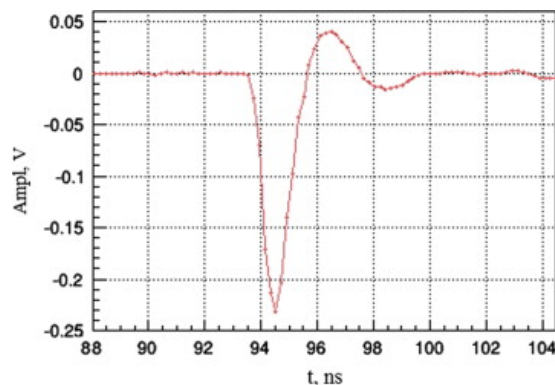
Two DRS4 waveform digitizer units [5] performed the main readout. The DRS4 were triggered by TTL level signals originating from the trigger counter. Signals from the four detectors, two Photek 240, the Photonis 85011-501 and the Cherenkov counter were split by high frequency Mini-Circuits ZFRSC-42-S+ splitters (4.2GHz BW). The outputs were connected in the same order to two DRS4 units. We attenuated the input signals to one of the two DRS4 units to cover the full dynamic range of the measurements. The other DRS4 did not have any additional attenuation. The schematic of the readout with the DRS4 units is shown in Fig. 1.



**Figure 1.** (Left) Test beam setup, located in the dark box. A Cherenkov counter was located before the dark box (not visible in the picture). (Right) A schematic of the readout. Attenuators were placed on channel 2 (CH2) and channel 3 (CH3).

#### 4. Event selection and analysis

To assign a time stamp for each signal pulse, we first determine the time position of the pulse peak. A Gaussian function is fitted to the pulse maximum using three points before the maximum of the pulse peak and four points after the maximum (sample pulse is shown in Fig. 2). The mean value of the Gaussian was used as the time stamp for each pulse. Large signals above 500 mV were also rejected because they saturated the DRS4 inputs. Pulses with an irregular peak profile were rejected, as well as pulses which experienced a sudden reversal of polarity that is occasionally observed with our readout. We selected the pulses with amplitude larger than 20 mV for future analysis.



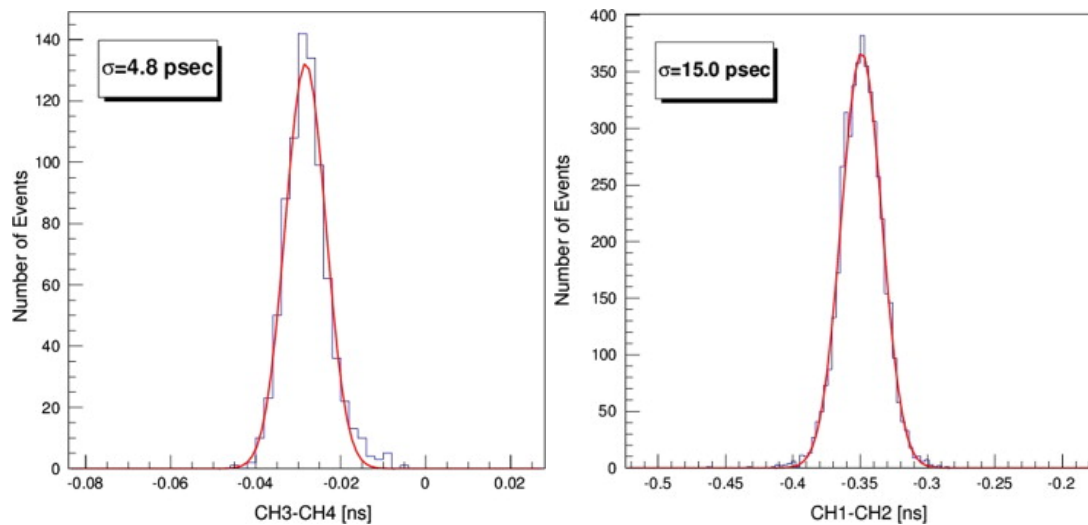
**Figure 2.** Signal of the Photek 240 recorded with a DRS4 during a run with 120 GeV/c protons passing through the PMT input window.

#### 5. Test beam measurements

First we measured the electronic time resolution of the DRS4 units. The signal from one of the Photek 240 detectors was split into two equal parts, and connected to adjacent channels on the same DRS4 unit. The distribution of the time difference between these two channels was measured, and fitted with a Gaussian. The standard deviation of this Gaussian is defined as the time resolution. The measured electronic time resolutions of the two DRS4 units were different, but it was small with respect to the time resolution obtained later on. The result was dependent on the signal amplitude and was 4.8 ps (sigma, Gaussian fit) for one DRS4 and 6.7 ps for the other one at the same signal amplitude. We attribute the difference to the higher input noise in one of the two DRS4 units, which was an earlier version of the device. Distribution illustrating electronic time resolution of the DRS4 is shown in Fig. 3.

Next we measured the resolution of the two Photek 240 placed in a line close to each other. Signal of the one of them was used as “start” and another one as “stop”. No lead plates were used between the start and stop counters (both of them were Photek 240) in the measurements. The time difference between the start and stop signals was measured. The Cherenkov light from 120 GeV protons in the Photek 240 input window created the signals in the MCP-PMT. The standard deviation of the Gaussian fit to the time difference between the two Photek 240, obtained with 120 GeV/c protons, was found to be 15.0 ps, as shown in Fig. 3. Assuming that the resolution of both Photek 240 is the same, one can derive the time resolution of a Photek 240 to be  $15.0/\sqrt{2} \approx 10.6$  ps.

Next measurements were performed with positively charged particles of the 12 GeV/c secondary beam. We refer to these measurements as “shower-max” (SM) below. The goal of the measurements was to measure the dependence of the detector signal amplitude and time resolution on the lead thickness. We made some measurements with different quartz plates installed in optical contact with the Photonis 85011-501 detector input window to estimate the contribution of Cherenkov light into the MCP-PMT response. The plates were made of UV



**Figure 3.** (Left) Distribution presenting electronic time resolution of the DRS4, and a Gaussian fit for it. In this setup the signal in channels 3 and 4 is identical, originating from one of the Photek 240 detectors, and is split into two equal parts. (Right) Spectrum presenting time resolution for the two Photek 240 in line, obtained with the 120 GeV/c proton beam. No lead plates between start and stop counters were used in the measurement.

Grade Fused Silica with the thickness of 3.5 mm and 7 mm. The stack of the lead plates with total thickness of either 10 mm or 20 mm was placed close to the Photonis 85011-501 input window. The transverse size of each set of the lead well covered the transverse size of the MCP-PMT.

We found that it is also possible to identify positrons using the signal of the downstream Photek 240. For positron events large signals near the end of the dynamic range of the unattenuated channel were produced. Using positron events selected by the gas Cherenkov counter we found the efficiency of the amplitude selection with the downstream Photek 240 to be 97%. We present the pulse height (PH, attenuated channel) and time distribution for zero and 3.5 mm quartz plates thickness placed upstream of the Photonis 85011-501 in Fig. 4.

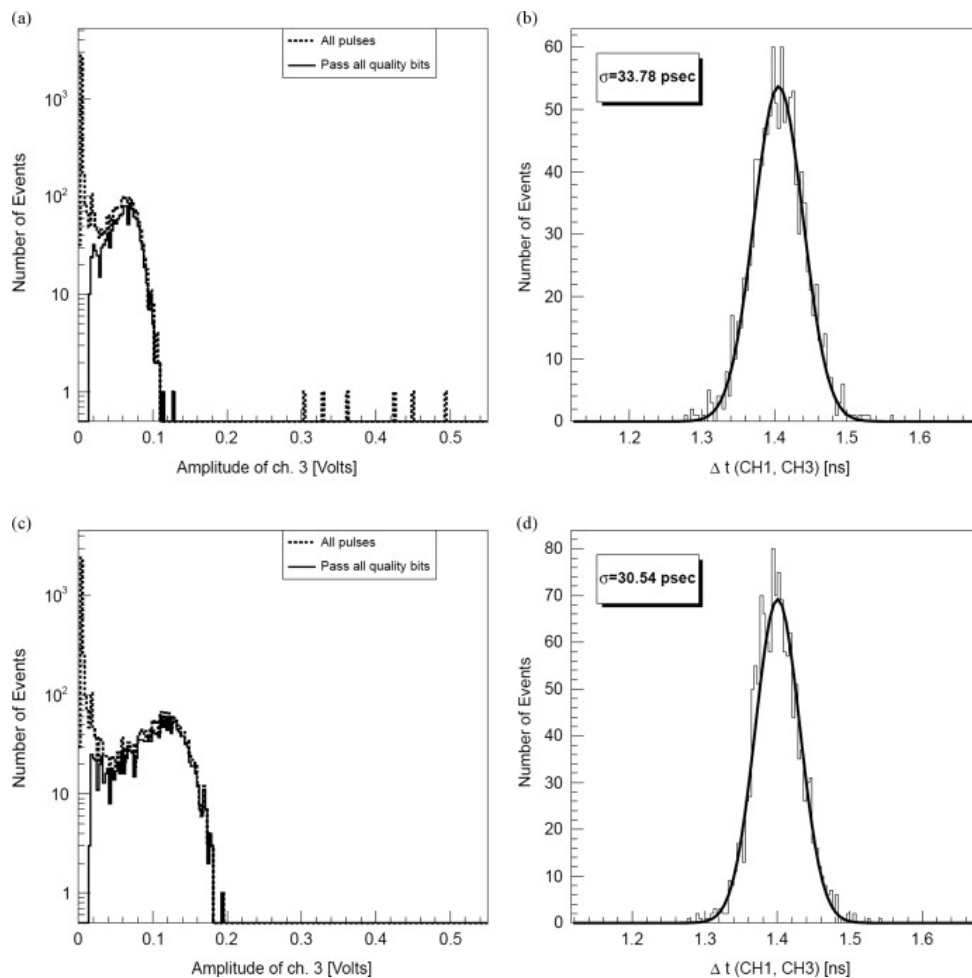
Fig. 5 shows dependences of the PH and TR distributions on the quartz plate's thickness.

The measurements described above were repeated with Photek 240 as the SM detector in the 12 GeV/c secondary beam. No additional quartz was attached to the input window. We measured TR of the SM as a function of the lead thickness. The obtained TR values equal to 27.3 ps, 22.2 ps and 23.5 ps for the lead thickness of zero mm, 10 mm and 20 mm, Fig. 6.

The next series of measurements with the SM was performed at 32 GeV/c. We used the downstream shower maximum detector (Photek 240) to select positrons with the 32 GeV/c beam. According to our estimation the positrons component in the beam was less than 10%. We carried out the measurements with 10 mm, 20 mm of lead thickness and without lead. The TR dependence on absorber length is shown in Fig. 6.

## 6. Discussion

The obtained data indicated that the shower particles were registered through the Cherenkov radiation in the input window as well as through direct interaction with the MCP. The secondary emission component of the response looks significant. Under the assumption that the Cherenkov response increases linearly with the radiator thickness (Fig. 5), one can extrapolate the dependence of the PH on the thickness of the Photonis 85011-501 input window down to

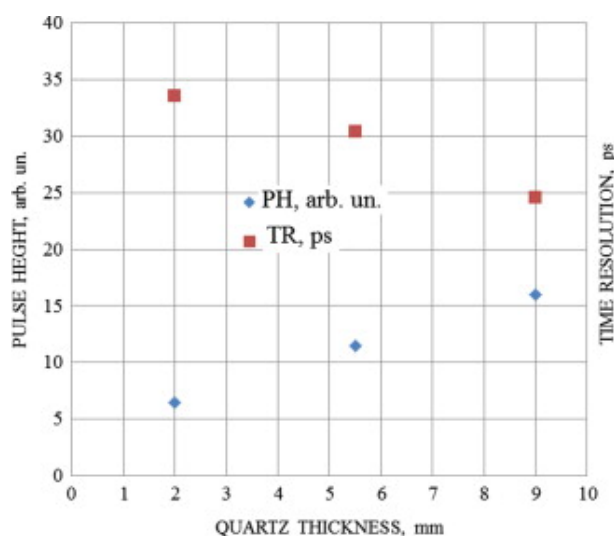


**Figure 4.** Distributions of the Photonis 85011-501 pulse height and the time difference between the start Photek 240 and Photonis 85011-501. Two pictures at left (a and b): no quartz plate is attached to the Photonis 85011-501 window. Two right pictures (c and d): 3.5 mm quartz plate is attached to the Photonis window. The other conditions are: 12 GeV/c, 10 mm of lead before the Photonis 85011-501.

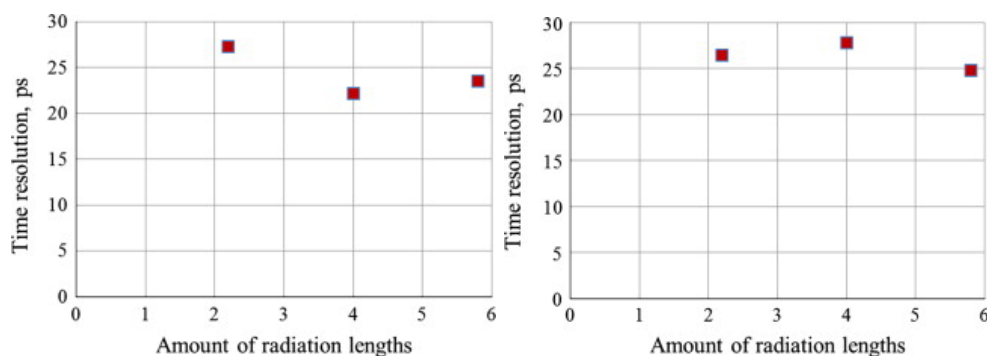
zero to get an estimate for the secondary emission. We can estimate that 70% of the Photonis 85011-501 response is due to the MCP secondary emission and 30% is due to Cherenkov light produced in the 2 mm thick input window. The TR of the secondary emission component can be estimated to be around 35-40 ps for the Photonis 85011-501.

The Photek 240 shows an even better SM TR, at the level of 20-30 ps. The Photek 240 has an input window thickness of 9 mm. We did not make measurement with different input window thickness, but we have seen the response increase with additional radiator optically coupled with the Photek 240 input window. Nevertheless we can assume that the low energy component of the shower detected by an MCP will be significant, no matter which device is used.

The measured main parameters of the electromagnetic shower are well described. The SM detector, (1-100 GeV electron energy) is usually located in the beginning of the shower, after less than  $4X_0$  - absorber thickness. We used lead thickness in correspondence with the SM locations in described detectors. The transverse size of the shower is very small at such depth and allows good separation from other showers. Our SM detectors cover this transverse size for lead absorber. The presented results show that the TR is at the level of 20-30 ps. The SM based



**Figure 5.** PH and TR dependences on absorber thickness in radiation length units. Photonis 85011-501 as SM, beam momentum is 12 GeV/c.



**Figure 6.** Dependence of the TR on the absorber thickness (in units of radiation length). Photek 240 as SM, 12 GeV/c (left) and 32 GeV/c (right) positrons beam.

on the approach could be very economical. A sandwich type calorimeter based on the same principle (MCP for all active layers) is also possible to build, but the cost is still a question in such a design.

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